

# **RISKS FROM THE TRANSPORT OF EXPLOSIVES**

**By**

**G E WILLIAMSON, HM CHIEF INSPECTOR OF EXPLOSIVES**

**HEALTH AND SAFETY EXECUTIVE  
H M EXPLOSIVES INSPECTORATE  
MAGDALEN HOUSE  
STANLEY PRECINCT, BOOTLE  
MERSEYSIDE L20 3QZ UK  
UNITED KINGDOM**

## **SUMMARY**

---

1. A recent study and report <sup>(1)</sup> on the major hazard aspects of the transport of dangerous substances has made an importance contribution to the development of QRA methodologies and criteria for assessing the risks involved in the movement of explosives articles and substances.
2. Some of the key issues are discussed in looking ahead at the extension of the study from road and rail transport to the risks from explosives in ports. See also R Merrifield/P A Moreton this seminar.
3. The programme to license the ports and harbours around the coastline of Great Britain which handle military and commercial explosives <sup>(2)</sup> is now completed. It has generally led to significant reductions in the amounts of explosives which may be handled. This reflects the scale of redevelopment in and around ports but also challenges the validity of established QD relationships as the proper basis for assessment.
4. Reduced ports limits also pose problems back up the logistical chain which may need to be taken into account in the overall safety equation. QRA cannot itself provide the answer but will inform the judgemental process.

## **ACDS STUDY OF MAJOR HAZARDS IN TRANSPORT**

---

5. The so-called ACDS study, completed for the Health and Safety Commission under its Advisory Committee on Dangerous Substances, embraced the quantified risk

| Report Documentation Page  |                                    |                                     |   | Form Approved<br>OMB No. 0704-0188                  |                                 |
|--|------------------------------------|-------------------------------------|---|---|---------------------------------|
| Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. |                                    |                                     |   |   |                                 |
| 1. REPORT DATE<br><b>AUG 1992</b>  |                                    | 2. REPORT TYPE                      |   | 3. DATES COVERED<br><b>00-00-1992 to 00-00-1992</b> |                                 |
| 4. TITLE AND SUBTITLE<br><b>Risks from the Transport of Explosives</b>   |                                    |                                     |   | 5a. CONTRACT NUMBER                                 |                                 |
|  |                                    |                                     |   | 5b. GRANT NUMBER                                    |                                 |
|  |                                    |                                     |   | 5c. PROGRAM ELEMENT NUMBER                          |                                 |
| 6. AUTHOR(S)   |                                    |                                     |   | 5d. PROJECT NUMBER                                  |                                 |
|  |                                    |                                     |   | 5e. TASK NUMBER                                     |                                 |
|  |                                    |                                     |   | 5f. WORK UNIT NUMBER                                |                                 |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br><b>Health and Safety Executive, Magdalen House, Stanley Precinct, Bootle, Merseyside L20 3QZ United Kingdom,</b>   |                                    |                                     |   | 8. PERFORMING ORGANIZATION REPORT NUMBER            |                                 |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)  |                                    |                                     |   | 10. SPONSOR/MONITOR'S ACRONYM(S)                    |                                 |
|  |                                    |                                     |   | 11. SPONSOR/MONITOR'S REPORT NUMBER(S)              |                                 |
| 12. DISTRIBUTION/AVAILABILITY STATEMENT<br><b>Approved for public release; distribution unlimited</b>  |                                    |                                     |   |   |                                 |
| 13. SUPPLEMENTARY NOTES<br><b>See also ADA260984, Volume I. Minutes of the Twenty-Fifth Explosives Safety Seminar Held in Anaheim, CA on 18-20 August 1992.</b>  |                                    |                                     |   |   |                                 |
| 14. ABSTRACT   |                                    |                                     |   |   |                                 |
| 15. SUBJECT TERMS  |                                    |                                     |   |   |                                 |
| 16. SECURITY CLASSIFICATION OF:  |                                    |                                     | 17. LIMITATION OF ABSTRACT<br><b>Same as Report (SAR)</b> | 18. NUMBER OF PAGES<br><b>11</b>                    | 19a. NAME OF RESPONSIBLE PERSON |
| a. REPORT<br><b>unclassified</b>   | b. ABSTRACT<br><b>unclassified</b> | c. THIS PAGE<br><b>unclassified</b> |   |   |                                 |

assessment (QRA) of the road and rail transport of chlorine, ammonia, liquified petroleum gas and motor spirit, the road and rail transport of explosives substances and articles, as well as the ports risks for handling of non-explosive substances in bulk.

6. The Report <sup>(1)</sup> describes and discusses in some detail the methods used and sets out the findings and recommendations which emerged. It argues that the principal risks in the transport of dangerous substances have been evaluated sufficiently for conclusions to be drawn about the overall national situation. It also makes suggestions on ways to reduce risks to 'as low as is reasonably practicable' (ALARP) and methods for that assessment. None of the risks studied were judged intolerable but on the other hand few could be regarded as negligible.
7. Criteria developed to judge the tolerability of individual and societal risks adds a further dimension to the debate prompted by earlier publications <sup>(3)</sup> <sup>(4)</sup> <sup>(5)</sup>.
8. Foremost amongst other findings reported is the importance of management in minimising risks by providing, promoting and maintaining safety systems and standards <sup>(6)</sup> <sup>(7)</sup>.

## **ROAD AND RAIL TRANSPORT OF EXPLOSIVES**

---

9. Not surprisingly given the many different types and load sizes of explosives, the method of assessment proved much more elaborate than for other substances studied. There was some read-across, for example of the method used to calculate population densities along routes or in the application of risk criteria. But a number of techniques were used to bring the study of explosives within manageable proportions and which could have wider application and interest.
10. In summarising the main stages of the assessment process in the following paragraphs, the aim has been to highlight some of those techniques.

### **CATEGORISATION OF EXPLOSIVES**

11. An important part of the methodology for assessing rates of occurrence for different types and sizes of explosives events was the categorisation of explosives into just seven groups. All explosives in a particular group could then be treated as if equally vulnerable to initiating stimuli and produce similar effects if initiated.

12. Data on rail and road explosives traffic could then provide two initial outputs; estimates of overall annual traffic volumes and estimates of the relative proportions of the various categories of explosives moved.

**TABLE 1**

| H.D | CATEGORY | RAIL WAGONS                 | ROAD VEHICLES             |
|-----|----------|-----------------------------|---------------------------|
|     |          | 2.6 X 10 <sup>6</sup> Km/yr | 4 X 10 <sup>6</sup> Km/yr |
|     |          | %                           | %                         |
| 1.1 | 'M'      | 0                           | 51                        |
|     | 'N'      | 16                          | 23                        |
|     | 'P'      | 11                          | 20                        |
| 1.2 | 'Q'      | 17                          | 2                         |
| 1.3 | 'R'      | 0                           | 3                         |
|     | 'T'      | 12                          | 1                         |
| 1.4 | 'W'      | 44                          | N/R                       |

M - heat sensitive substance in flammable packaging  
 N - heat sensitive article - not readily ignitable  
 P - heat sensitive substance  
 Q - heat sensitive article  
 R - heat sensitive substance in flammable packaging  
 T - heat sensitive substance or article in on-flammable packaging  
 W - heat sensitive article but no great hazard

No H.D 1.5 or 1.6 movements in UK. Fireworks not included.

13. There are significant differences between rail and road traffic patterns. Virtually all rail traffic is military and includes no more than 27% of H.D 1.1; half insensitive to heat and half not readily ignitable. Road traffic on the other hand includes up to 94% of H.D 1.1; over half heat sensitive substances in flammable packagings, a reflection of the commercial sector.

## FREQUENCY OF INITIATING EVENTS

14. Studies of the historical accident record for explosives traffic over the last 40 years suggested that fire or the presence of unsafe material are the two most likely causes of explosives events on rail and road vehicles. Unsafe in that sense meaning an explosive badly packaged, manufactured or otherwise out of specification or in breach of legal requirements. A number of crashes or collisions of vehicles had been recorded but in no case had that led to an explosives event; impact was however considered in the study.
15. The rates for dangerous occurrences involving fire or impact were deduced from the historical data or when necessary from fault tree analysis. FTA for example resolved the problem that rail wagon and road vehicle technology had improved since the one fire recorded for rail (axlebox) or the four recorded for road (various vehicle defects). A combination of accident data, trials data and expert judgement provided the conditional probabilities that an explosives event would result from a fire or impact accident.
16. The historical occurrence of events involving the initiation of unsafe explosives was used directly, on the assumption that management standards would at least remain constant over time.
17. There had, over the 40 year period, been one event due to unsafe explosives on the railway, one on the roads. The latter tragically leading to the death of a fire-fighter, the only fatal explosives transport accident in that time (6).
18. The derived frequency rates:

**TABLE 2**

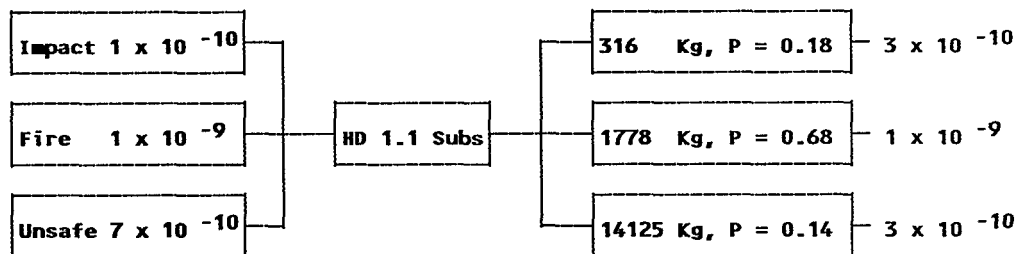
| Initiating Mechanism | Rate of Occurrences of Explosives Events |                                  |
|----------------------|--|----------------------------------|
|                      | Rail: Wagon - Km <sup>-1</sup>           | Road: Vehicle - Km <sup>-1</sup> |
| Unsafe Explosives    | 1 x 10 <sup>-9</sup>                     | 1 x 10 <sup>-9</sup>             |
| Fire                 | 6 x 10 <sup>-10</sup>                    | 2 x 10 <sup>-9</sup>             |
| Impact               | 1 x 10 <sup>-10</sup>                    | 2 x 10 <sup>-10</sup>            |

19. Initiation of unsafe material is significant for both modes, indeed considered - in view of the accident

record for explosives storage - to be one of the more probable causes of an event. The rate for fire-induced events is slightly higher for road than rail. On road vehicles, tyre fires were judged to be the major source of ignition.

## **PARTITIONING OF EXPLOSIVES EVENTS**

20. Because the consequences of an event on the road or rail would depend on both the type of explosive carried and on the quantity of explosives in the load, it was necessary to partition events to obtain a series of frequency rates which took both factors into account. This involved a complex plan of event trees and the input of data on representative load sizes obtained by maximum entropy analysis.
21. Use of that technique, resolved the practical problem that fatality estimates could not be calculated for all sizes of explosives loads transported by road and rail. The grouping of loads into a smaller number of notional sizes of cargo, like the grouping of explosives into categories, kept the study within manageable proportions.
22. An extract from an event tree outlining possible types and sizes of explosives events on road vehicles will illustrate the process. This shows the three nominal load sizes derived for substances of H.D 1.1 and the proportion of the overall mileage (P) each accrued. A total of 11 load sizes and corresponding rates of initiation were generated for road transport.



## **HAZARD RANGES**

23. Hazard ranges to 90%, 50%, 10% and 5% fatalities for each of the representative explosives loads moved by road and rail were calculated by reference to appropriate consequence models:
  - HD 1.1 effects were embraced by an analysis of twelve war-time V2 rocket attacks;

- HD 1.2 effects were based on worst case trials data, but limited to 50 Kg NEQ;
  - HD 1.3 effects were judged from available models for idealised and non-idealised fires.
24. The models undoubtedly introduced a number of uncertainties well recognised in the Report but the derived results were judged somewhat conservative in the context of a road or rail incident.
25. The hazard ranges as derived were limited in practice to about 87m, though fatalities could extend out to about 107m in an event involving communication between fully loaded rail wagons. It is however axiomatic that much wider injury and damage can result; the normal public evacuation distances for 16 te and 5 te of HD 1.1 explosives - regulatory limits for different kinds of road vehicle - are set at 560m and 380m respectively.

### POPULATION DENSITIES

26. The numbers of people encompassed by the hazard ranges from the representation loads depended on three factors:
- a) the extent of alongside clear zones, typically 25m for rail, 27.8m for motorways, 10m for dual carriageways, zero for single roads;
  - b) the density of alongside populations - urban 4210, suburban 1310, built-up rural 210 or rural 20 people per square kilometre;
  - c) the proximity of other route users - on rail in a passing passenger train, on road the build-up behind an explosives vehicle accident and the slowing down of traffic on the opposite side.

### RISK ANALYSIS

27. Estimates of the overall national risks from rail and road transport were made by reference to selected routes having the features which characterise routes generally. Two rail routes were chosen to reflect the different patterns of traffic on inter-city mainlines and on provincial and freight lines. The one road route included all three classes of road and went through both urban and rural areas.
28. The representative routes were first partitioned into the various sections which properly reflected the on-route and off-route population densities associated with them. By assuming that all of the national explosives

traffic passes in turn through each section, the frequencies with which different types of explosives events might occur and the corresponding fatality levels could be estimated. In the case of the road study this generated 308 f/n pairs; from 28 road sections and 11 load sizes.

29. Computation of f/n pairs provided overall frequencies of events leading to different numbers of fatalities in the bands considered:

| Frequency of N or more Fatalities (yr <sup>-1</sup> ) |                    |                    |                    |                    |
|---|--------------------|--------------------|--------------------|--------------------|
|   | N = 1              | N = 3              | N = 10             | N = 30             |
| Road  | 1x10 <sup>-2</sup> | 1x10 <sup>-2</sup> | 7x10 <sup>-3</sup> | 4x10 <sup>-4</sup> |
| Rail-mainline route                                   | 6x10 <sup>-4</sup> | 3x10 <sup>-4</sup> | 1x10 <sup>-4</sup> | 2x10 <sup>-6</sup> |
| Rail-provincial route                                 | 7x10 <sup>-4</sup> | 4x10 <sup>-4</sup> | 2x10 <sup>-4</sup> | 1x10 <sup>-6</sup> |

30. It was concluded after comparing those results with criteria developed as part of the wider study, and after taking into account the various uncertainties, that the national societal risks of transporting explosives by road and by rail are not intolerable but are at a level where they require reduction. En-route individual risks are considered minimal, though the risks at specific locations where they may be concentrated, such as at a rail marshalling yard with a high throughput and nearby population may require more detailed study.
31. Although the societal risks estimated for the rail transport of explosives were significantly lower than those for road, no conclusion could be drawn about the relative safety of the two modes; too many differences were revealed. The risks to off-road and off-rail populations were broadly similar. The predominant risk of road transport is that to other road users.
32. Risk reduction measures suggested by the study included:
- better fire protection of load-carrying compartments on vehicles, in particular from tyre fires;
  - active and passive systems to prevent spread of fire inside load carrying compartments;
  - phasing out of NG-based blasting explosives;
  - use of non-flammable dunnage in rail wagons;



- use of rail barrier wagons to prevent communication;
  - detailed study of any marshalling yard with a large throughput of explosives and a nearby population;
  - continued double-manning of explosives vehicles.
33. The final caution; estimates of risk should be used with care and not be taken out of the context of the study.

## **RISK CRITERIA**

---

34. It is outside the scope of this paper to set out a properly balanced discussion of risk criteria that might be appropriate in the explosives field or to make all of the necessary qualifications. The purpose here is merely to indicate in very broad terms some of the principles applied in the ACDS Report <sup>(1)</sup> and on which judgements about the tolerability of estimated risks were made.
35. Criteria for levels of risk for the transport of dangerous substances were developed within the conceptual framework of:
- intolerable, risks so high as to be socially and politically unacceptable regardless of any benefit that may accrue from them. Such risks call for immediate action to reduce them, irrespective of cost;
  - negligible, risks so small that they do not require action to be taken to reduce them;
  - ALARP, risks which fall into a band between the above two levels. Such risks though broadly tolerable should be reduced to a level that is 'as low as reasonably practicable' - the greater the risk, the greater the cost of reduction justified.

## **INDIVIDUAL RISK**

36. The risks to individuals living or working in the vicinity of fixed locations such as railway marshalling yards, lorry stop-overs and ports were judged against:
- a risk of death of  $10^{-3}$  or  $10^{-4}$  per year for workpeople and the public, respectively, as intolerable;
  - a risk of death of  $10^{-6}$  as broadly acceptable and of  $10^{-7}$  as truly negligible;

as levels relevant to existing risks to existing populations. Different criteria may be appropriate for the introduction of new risks to an existing population or an increase in population subject to an existing risk.

37. Individual risk was also used as a surrogate for societal risk, in particular to discuss the questions which arise in relation to land development for housing near to a fixed location. In essence, upper limits are set for the risk to an individual of receiving a dangerous dose of an effect such as over-pressure, one which could cause:
- severe distress to almost everyone;
  - medical attention for a substantial fraction of those exposed;
  - serious injury, requiring prolonged treatment to some;
  - death to any highly susceptible person.
38. The ACDS report roughly equated a 5% chance of death due to explosion effects to a dangerous dose in the event of an accident. The frequency with which any population at the 5% fatality hazard range would be exposed to a dangerous dose of blast over-pressure, say, is then equal to 20 times their individual risk of death. It would be unlikely to advise against a new housing development providing for about 25 people where the calculated individual risk of receiving a dangerous dose is less than  $10^{-5}$  per year. But concern would be expressed about new developments for more than about 75 people if the individual risk of receiving a dangerous dose exceeded  $10^{-6}$  per year. (Reference 4 suggests this corresponding to a risk of death at about  $3 \times 10^{-7}$  per year).

### SOCIETAL RISKS

39. ACDS noted the difficulties in determining universally relevant levels of tolerable and negligible societal risk and the many qualifications it is necessary to make. But during transport itself, the risks to any particular individual are much more transient and so less relevant than criteria for risk to the public in general.
40. The proposed societal risk criteria were based on the observation that risks at Canvey Island, in the south of England, were judged just tolerable after the most

searching technical and socio-political assessment. The risks there were seen as similar enough in nature to the risks in transport to allow this limited degree of read across, though some questions were raised about additional aversion factors in particular with respect to explosives.

41. A pair of parallel lines on an FN graph, with a slope of minus one were proposed as criteria for 'tolerable' and 'negligible' in one locality. The upper 'just intolerable' line passes through the 'Canvey point' ( $N > 500$ ,  $F = 2 \times 10^{-4}$  per year). The lower line corresponds to a predicted frequency a thousand times lower. Risks below this are regarded as negligible. Risks above the upper line are intolerable if concentrated in any one locality. Risks between the lines should be reduced so far as is reasonably practicable.
42. The problem inherent in comparing estimates of national societal risk against the local intolerability criteria were not fully resolved. But proposals were made for a 'national scrutiny level' of societal risk, determined by scaling up the tolerable risk per tonne of cargo handled at Canvey by the national volume of trade, and expressed as a further parallel line on the F/N graph. If national risk approaches this level it will not necessarily be intolerable, but should be looked at with special scrutiny.
43. A 'local scrutiny level' for societal risk at a particular fixed location, like a port, can be derived in a similar way; scaling in this case by the volume of trade at the port rather than the national volume. The level only has meaning if it falls below the local intolerability line referenced to Canvey.

## REFERENCES

1. Health and Safety Commission. Major Hazard Aspects of the Transport of Dangerous Substances: Report and Appendices. London HMSO 1991. ISBN 011 885676 6.
2. G E Williamson. The Licensing of Ports and Harbours Handling Explosives. Proceedings of 23rd DoD Explosives Safety Seminar, Atlanta 1988.
3. Health and Safety Executive. The Tolerability of Risk from Nuclear Power Stations. London HMSO 1988. ISBN 011 883982 8.
4. Health and Safety Executive. Risk Criteria for Land-Use Planning in the Vicinity of Major Industrial Hazards. London. HMSO 1989. ISBN 0 11 885491 7.
5. Health and Safety Executive. Quantified Risk Assessment: Its Input to Decision Making. London: HMSO 1989. ISBN 0 11 885499 2
6. G E Williamson. Safety Management in the Explosives Industry. Proceedings of 24th DoD Explosives Safety Seminar, St Louis, 1990.
7. Health and Safety Executive. Successful Health and Safety Management. London: HMSO 1991. ISBN 011 885988 9.